DESIGN ASSESSMENT USING MULTIZONE SIMULATION TO PROTECT CRITICAL INFRASTRUCTURE FROM INTERNAL CHEMICAL AND BIOLOGICAL THREATS

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ABSTRACT

Previous attacks in Tokyo and Washington, DC, have demonstrated the capability to weaponize and use chemical and biological (CB) agents against critical infrastructure. Critical infrastructure includes the defense industrial base whose primary mission is to design, test, and manufacture weapons systems in support of national defense. The U.S. Army's Future Combat Systems (FCS) Program alone involves 13 major defense contractors and more than 500 suppliers. Each contractor has multiple command and control offices, engineering and laboratory sites, and production facilities. Protection of these structures from an internal CB attack is essential to the successful development and fielding of the FCS. In this paper, a quantitative design assessment methodology is presented that will enable decision makers to assess building designs for CB protection. This methodology uses multizone simulation in combination with analysis of financial implications for different designs. The methodology provides the ability to measure the fraction of the building protected versus cost percent increases for a specific design. A hospital emergency room is used as a case study, but this methodology can be adapted for most buildings. This research project is based on public domain literature and software applications, thereby making it available to all building designers.

1. INTRODUCTION

The March 1995 release of sarin gas in a Tokyo subway and the September 2001 mailing of letters containing weaponized anthrax demonstrate the significant threat posed by chemical and biological (CB) attacks on critical infrastructure. Those two attacks caused 17 deaths and exposed more than 5000 people to harm. More recently, the February 2004 ricin-laced letters and the February 2006 sensor detection of a possible nerve agent resulted in the evacuation of the Dirksen and Russell Senate Office Buildings, respectively. Although no one was harmed, these events immediately disrupted congressional activities.

In response to CB threats, federal and Department of Defense (DoD) laboratories are conducting intensive research in the area of "immune buildings." ERDC-CERL is using computational fluid dynamics (CFD) to model CB dispersion within military facilities. The Defense Advanced Research Projects Agency (DARPA) Immune Building Program has developed an Immune Building Toolkit that uses multizone software to assess CB threats inside buildings. Sandia National Laboratories is using both CFD and multizone programs in its Chemical/Biological Program. Because those studies pertain strictly to military and government infrastructure, the work remains classified or for official government use only.

The defense industrial base is one of the 17 critical infrastructures specified in a recent presidential directive. The National Critical Infrastructure Protection Research and Development Plan assigns the DoD with the responsibility of assessment and protection of those facilities. The Army's Future Combat Systems (FCS) Program currently involves 13 major defense contractors and more than 500 suppliers. The participating organizations have multiple command and control offices, engineering and laboratory sites, and production facilities. Protection of those facilities from an internal CB attack is essential to preserving the nation's ability to design, test, and manufacture the FCS.

To address this requirement, collaborative research is under way by Purdue University, West Lafayette, IN, and ERDC-CERL. The principal research objective is to develop a cost-effective, quantitative methodology to assess complex protective designs that maximize the security of critical infrastructure against internal CB threats. This research extends the modeling and simulation work of federal and DoD laboratories by incorporating a financial comparative cost analysis as part of the assessment. The methodology presented here is also cost-effective because it requires significantly fewer resources than CFD-based methods. In this research effort, investigations have focused on time-dependent concentration distributions following an internal release,

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time variation of the fraction of the building exposed, impacts of CB protection options, and determination of the fraction of the building protected. All products of this research remain in the public domain to promote open publication and transfer to the defense industrial base.

2. RESEARCH METHODOLOGY

This quantitative methodology employs a public domain multizone program called CONTAM, which is available from National Institute of Standards and Technology's website (NIST 2006). The CONTAM program creates multizone building models and simulates interzonal airflow and contaminant transport. Once the building characterization data are developed, CONTAM calculates zone pressures and airflow rates through each flow path by performing a simultaneous mass balance of air in all zones. CONTAM assumes uniform mixing in each zone. Contaminant information and airflows are then used to determine concentrations within each zone. The mass flow rate along a given airflow path, from zone *j* to zone *i*, is a function of the pressure difference between zones. The conservation of mass is applied to all zones, which results in a set of nonlinear algebraic equations that must be solved iteratively. Zonal pressures and mass flow rates for all zones and airflow paths are calculated using numerical methods. After the mass flow rates are computed, conservation of mass is used to determine the contaminant mass in each zone. The differential equation shown in Equation 1 provides the basis for contaminant dispersion calculations within a building.

$$[dm_{\alpha,i}/dt] = -R_{\alpha,i}C_{\alpha,i} - \sum_j F_{i,j}C_{\alpha,i} + \sum_j F_{j,i}(1 - \eta_{\alpha,j,i})C_{\alpha,j} + m_i \sum_\beta \kappa_{\alpha,\beta}C_{\beta,i} + G_{\alpha,i} \quad (1)$$

where: $[dm_{\alpha,i}/dt]$ = time dependent contaminant mass
$R_{\alpha,i}C_{\alpha,i}$ = contaminant removal rate where $R_{\alpha,i}$ is the removal coefficient
$\sum_j F_{i,j}C_{\alpha,i}$ = outward airflows from the zone where $F_{i,j}$ is the rate of airflow from zone *i* to zone *j*
$\sum_j F_{j,i}(1 - \eta_{\alpha,j,i})C_{\alpha,j}$ = inward airflows where $\eta_{\alpha,j,i}$ is the filter efficiency for contaminant α in the path from zone *j* to zone *i*
$m_i \sum_\beta \kappa_{\alpha,\beta}C_{\beta,i}$ = first-order chemical reactions with other contaminants $C_{\beta,i}$ where $\kappa_{\alpha,\beta}$ is the kinetic reaction coefficient in zone ii between species α and β
$G_{\alpha,i}$ = generation rate of contaminant

A difference equation is used to approximate this differential equation. It is then solved using a fully implicit numerical approximation (Dols 2001).

This multizone approach was selected over CFD for its faster computational time, public availability, and minimal training requirement. These benefits make it a very cost-effective and attractive tool for building designers. DARPA has developed an Immune Building Toolkit that uses CONTAM to assess CB building threats.

For each zone, CONTAM generates results in kilograms of contaminant per kilograms of air (kg_{cont}/kg_{air}). A data transformation step is required before the results can be assessed against published dosage levels for the specific chemical or biological agent. This transformation is implemented in a spreadsheet and uses Equations 2 and 3 for gaseous and particulate contaminants, respectively.

$$\frac{kg_{cont}}{kg_{air}} = \frac{(ppm_{cont}) \times (MW)}{(1 \times 10^{-6}) \times (V_s) \times (\rho_{air})} \quad (2)$$

$$\frac{kg_{cont}}{kg_{air}} = \frac{\#}{m^3} \times \frac{\rho_{eff}}{\rho_{air}} \times \frac{\pi D^3_{mean}}{6} \quad (3)$$

where: ppm_{cont} = parts per million of contaminant
MW = molecular weight of the contaminant in kg_{cont}/kmol
1×10^{-6} = unit conversion for ppm_{cont}
$V_s = 24.05\ m^3$/kmol, the volume of one mole of air at 20 °C and 1 atm
$\rho_{air} = 1.204\ kg/m^3$ at 20 °C
\# = number of particles per m^3
ρ_{eff} = effective particle density in kg/m^3
D_{mean} = mean diameter of the contaminant particle (Walton and Dols 2005)

As part of the data transformation, assumptions about respiration are needed to determine the level of occupant exposure. The exposure levels are based on an average 70 kg male. A minute volume (MV) of 15 L (PMCBAC 2005) and a tidal volume of 10 – 15 mL/kg are assumed (Begany 2000). The MV volume is the volume of air exchange in 1 minute and the tidal volume is the amount of air inhaled or exhaled with each breath. Not all of the tidal volume takes part in respiratory exchange because that process does not start until the air or gas reaches the respiratory bronchioles. There is anatomical dead-space of approximately 2 mL/kg, or 150 mL in an adult, which is roughly a third of the tidal volume (Roberts 2000). Based on these respiratory assumptions, an average of 18 breaths per minute is used in this study.

Table 1. Estimated Dosage Levels for Chemical Contaminants (adapted from PMCBAC 2005)

Name	Molecular Weight [kg/kmol]	Exposure Duration [min]	Lethal Effects based on LCt_{50}, [mg·min/m^3]	Severe Effects based on ECt_{50}, [mg·min/m^3]	Mild Effects based on ECt_{50}, [mg·min/m^3]
VX	267.37	all	15	10	0.1
Sarin (GB)	140.09	2	35	25	0.4
		10	60	45	0.6
		30	86	60	0.9
		60	110	80	1.1
		120	140	100	1.4
Hydrogen Cyanide (AC)	27.03	2	2860	unknown	unknown
		10	6070	unknown	unknown
		30	20,630	unknown	unknown

Table 2. Estimated Dosage Levels for Biological Contaminants (CDC 2004, 2003)

Name	Molecular Weight [kg/kmol]	Lethal Effects, LD_{50}
Anthrax	N/A	8000 – 40,000 particles
Ricin	64,000	350 – 700 µg

To determine the level of exposure to a specific contaminant, published values for mild, severe, and lethal effects were obtained and summarized in Tables 1 and 2. For the two nerve agents, VX and sarin, mild effects can include miosis, rhinorrhea, and tight chest; severe effects include prostration, collapse, and convulsions (PMCBAC 2005). Dosages for all listed chemical and biological agents are limited to inhalation and ocular exposure only. For the purposes of this study, LD_{50} values of 8000 particles and 350 µg were selected for anthrax and ricin, respectively. Additionally, a mean diameter of 1.118 µm and an effective density of 1100 kg/m^3 are used for anthrax (Kowalski 2003).

For each zone, a cumulative exposure amount is assessed against the mild, severe, and lethal dosage levels. Values for the fraction of building exposed (FBE) and fraction of the building protected (FBP) are calculated based on Equations 4 and 5.

$$FBE = \frac{\sum \text{Area\_Exposed}}{\sum \text{Total\_Area}} \quad \text{for } FBE_{\text{mild, severe, lethal}} \tag{4}$$

$$FBP = 1 - (FBE_{mild} + FBE_{severe} + FBE_{lethal}) \tag{5}$$

For the baseline building design, CONTAM simulations are conducted and the corresponding values for the FBE and FBP are determined for each chemical and biological agent.

Financial costs for the building's air handling system are divided into mechanical/electrical (ME) and operation and maintenance (OM) categories. The ME category includes all one-time initial costs and OM accounts for recurring costs. Those costs are classified as baseline ME and OM costs. Redesign options are developed in an attempt to improve the building's CB protection level. All costs associated with a redesign option are categorized as an additional ME or OM cost. Values for the mechanical/electrical percent increase (MEPI) and the operation and maintenance percent increase (OMPI) are determined by Equations 6 and 7 for each redesign option. The MEPI and OMPI represent the percent increase in cost above the respective baseline cost.

$$MEPI = \frac{\text{Additional\_ME\_Costs}}{\text{Baseline\_ME\_Costs}} \tag{6}$$

$$OMPI = \frac{\text{Additional\_OM\_Costs}}{\text{Baseline\_OM\_Costs}} \tag{7}$$

MEPI accounts for new equipment, modifications, and installation costs. The OMPI is traditionally assumed on an annual basis, and consists of utility, maintenance, and filter costs. If CB detectors are used, costs for calibration and test samples are included as well. A building cost percent increase (BCPI) is calculated by summing the additional costs for ME and OM and dividing that value by the total ME and OM baseline costs, as shown in Equation 8.

$$BCPI = \frac{(\text{Additional\_ME\_Costs} + \text{Additional\_OM\_Costs})}{(\text{Baseline\_ME\_Costs} + \text{Baseline\_OM\_Costs})} \tag{8}$$

The BCPI can be calculated for any time period, but for the purposes of this study it will represent total building costs for the first year. For each redesign, a CONTAM simulation is performed and an FBP is calculated and linked to its corresponding MEPI, OMPI, and BCPI. This process is repeated until all selected redesign options have been completed.

Selection criteria for the best redesign option will vary depending on the priority established by the decision maker. Maximizing the FBP, minimizing the ME costs, lowering the annual OM costs, and total budget are possible selection criteria. Depending on the concept of operations, immediate evacuation of the building may not be feasible, therefore requiring more expensive CB

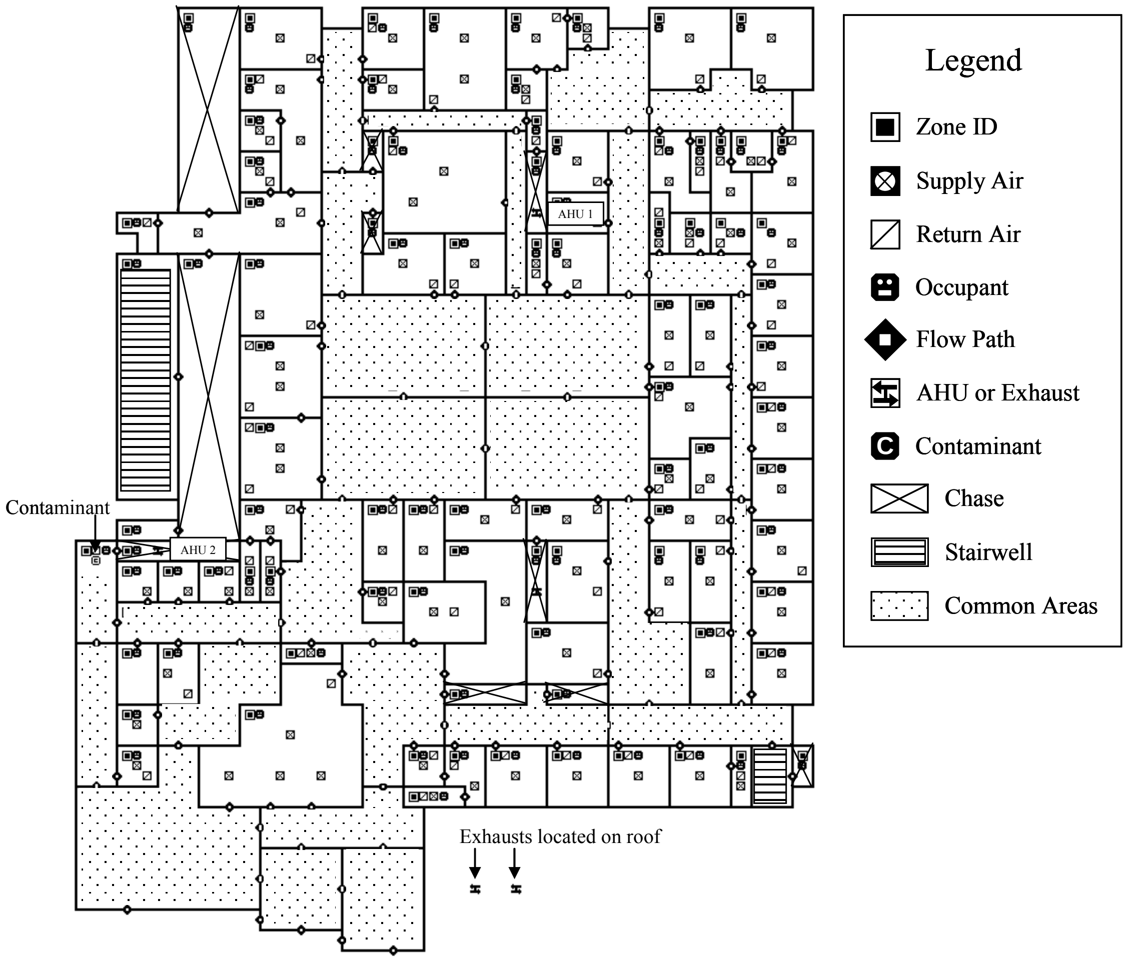

Fig. 1. CONTAM baseline model of emergency room

protection options. Combinations of several criteria can be analyzed together, providing the decision maker with an efficient means of comparing multiple design options.

3. CASE STUDY

To illustrate the research methodology described above, a case study is now considered. In this study, the complex critical infrastructure selected for modeling is a hospital emergency room (ER). The ER was selected because it incorporates a complex air handling system, encompasses both public access and secured areas, and includes special features such as positive- and negative-pressure isolation rooms. For analysis purposes, the baseline is a conventional design that includes particulate filtration intended to reduce the spread of biological pathogens. Beyond its conventional hospital design, this ER does not incorporate any additional CB protection measures. Although a hospital ER is being modeled, this design assessment methodology is flexible and can be adapted for most buildings, including new construction or a renovation.

The 1840 m^2 emergency room depicted in Figure 1 consists of 76 rooms that are modeled as 105 occupant zones within the CONTAM program. Larger rooms are subdivided into smaller zones to increase the accuracy of the model. Two air handling units (AHUs) supply conditioned air with a total design flow rate of 9.09 m^3/s (19,260 cfm). More than 200 supply and return points are incorporated into the model, with flow rates between 0.00118 – 0.4484 m^3/s. The two exhaust icons located outside of the ER figure represent venting of the negative isolation rooms and staff kitchen to the roof. Under normal operating conditions, the ER uses a 20% outdoor air (OA) to 80% recirculated air (RA) mixture. Each AHU uses minimum efficiency reporting value (MERV) 7, 12, and 14 particulate filters in series to treat the OA and RA. For modeling purposes, only MERV 14 filters are incorporated in the CONTAM model.

Baseline simulations involve the individual release of chemical and biological contaminants. Chemical contaminants include VX, sarin, and hydrogen cyanide in release amounts of 4 kg each. Biological agents consist of anthrax and ricin, with 2 g being released. Each contaminant is released over the initial 10 minute period and assumed to disperse entirely into the air. Based upon a review of the open literature, the contaminant type and release quantities are realistic and consistent with possible threat scenarios. The contaminant release occurs in a lobby zone that is accessible to the public.

Each simulation is conducted for 120 minutes at 1 minute time steps.

CB protection redesign options are developed to improve the FBP. As summarized in Table 3, these options fall into the categories of AHU operation, AHU filtration, AHU additions, and CB detection. The mechanical/electrical (ME) category considers costs for the new equipment and installation, or the modification to existing equipment. Operation and maintenance (OM) costs are primarily focused on increased utility and maintenance requirements, filter type, and usage. If a CB detection system is employed, OM costs will include supplies required for calibration and periodic testing of the equipment.

Table 3. Cost Categories for CB Protection Redesign Options

CB Protection Redesign Options	ME	OM
AHU Operation		
Air mixture ratio: OA to RA ratio		X
Dilution ventilation: initiating 100% OA		X
Shutdown: turning off AHU		X
AHU Filtration		
MERV particulate filters	X	X
Charcoal/carbon filters	X	X
Ultraviolet germicidal irradiation (UVGI)	X	X
AHU Additions		
Install separate exhaust systems	X	X
Install additional AHU	X	X
CB Detection		
Install sensors for early detection	X	X

These specific redesign options were selected based on current methods of improving indoor air quality and CONTAM's ability to incorporate them. Specific redesign options will differ depending on whether the building is new construction or a renovation. Tailoring these options for the specific structure is essential to maximizing CB protection.

Selected CB protection redesign options were determined through discussions with the resident hospital facilities manager and listed in Table 4. Selection of redesign options was limited due to AHU capacities, hospital design codes, and feasibility of incorporating specific options. The current AHUs are operating at their maximum capacity. A higher MERV particulate filter would require an increased AHU flow capacity, but that is not feasible for the hospital. Additionally, hospital codes require the use of MERV particulate filtration. Although ultraviolet germicidal irradiation (UVGI) can improve biological contaminant protection, its reliability and performance has not been accepted into practice. Charcoal/carbon filters would require significant modification of the existing AHUs. They would also require a higher flow capacity which, again, is not feasible for the hospital.

Table 4. Selected CB Protection Redesign Options for the Emergency Room

CB Protection Options	Description
AHU Operation	
Air mixture ratio	OA/RA ratio from 20/80 to 40/60 in increments of 5%
Dilution ventilation	100% OA initiated at 5 and 30 minutes after release
Shutdown of AHUs	AHU shutdown initiated at 5 and 30 minutes after release
Additional AHU Equipment	
Separate exhaust systems	Separate lobby exhaust initiated at 5 and 30 minutes
Install additional AHU	Separate AHU for lobby
CB Detection	
Install sensors	Early detection results in response actions at 5 minutes

A total of 15 redesign options were analyzed in an attempt to improve CB protection for the ER. Table 5 lists each option along with its corresponding MEPI, OMPI, and first-year BCPI.

Table 5. Redesign Options Cost Analysis

Redesign Option	MEPI	OMPI	BCPI
Change OA/RA to 25/75	0	0.021	0.006
Change OA/RA to 30/70	0	0.043	0.013
Change OA/RA to 35/65	0	0.064	0.019
Change OA/RA to 40/60	0	0.086	0.025
100% OA at 5 min	0.630	0.080	0.469
100% OA at 30 min	0	0.004	0.001
Shutdown AHU at 5 min	0.630	0.076	0.468
Shutdown AHU at 30 min	0	0	0
Separate exhaust at 5 min	0.945	0.078	0.691
Separate exhaust at 30 min	0.315	0.002	0.223
Additional AHU at 20/80	0.787	0.238	0.627
Additional AHU at 25/75	0.787	0.255	0.632
Additional AHU at 30/70	0.787	0.276	0.638
Additional AHU at 35/65	0.787	0.300	0.645
Additional AHU at 40/60	0.787	0.330	0.654

The baseline ME cost for the AHU portion of the ER renovation is $63,500. Annual baseline OM costs for utilities and filters are $11,245 and $15,000, respectively. The AHU MERV 7, 12, and 14 particulate filters have to be replaced approximately every 6 months. Changing the OA/RA ratio increases utility costs by 5% for each 5% increase in OA. A CB sensor system in the lobby that would detect and respond at 5 minutes is estimated at $40,000 with a $2000 annual maintenance cost. A separate exhaust system and AHU for the lobby zones is priced at $20,000 and $50,000. A 20% increase in utility costs is added for each 5% increase in OA for the dedicated lobby AHU, with additional annual filter costs of $4000.

4. RESULTS

For chemical agents VX and sarin, the FBP for the majority of designs declined 24% after 2 minutes, and went to zero by 10 minutes. The potent lethality for VX

and sarin resulted in the ER achieving and surpassing the mild exposure level quickly. In order to report a higher level of sensitivity, the FBP values were recalculated for severe and lethal effects only. For the biological agents (anthrax and ricin), the FBP is based on lethal effects only. These values are shown in Table 6.

Table 6. Fraction of Building Protected (FBP) for Baseline Design

Contaminant	Fraction of Building Protected (FBP) by [min]				
	2	10	30	60	120
VX	0.784	0.706	0	0	0
Sarin	0.848	0.741	0	0	0
Hydrogen Cyanide	1.000	0.989	0.823	NA	NA
Anthrax	0.771	0.710	0.684	0.684	0.684
Ricin	0.989	0.989	0.836	0.802	0.788

Table 6 results are consistent in terms of the expected performance of the baseline ER model. The ER uses high-level MERV particulate filters to reduce the spread of biological contaminants, such as pathogens that are particulate in nature. The FBP for lethal anthrax exposure remains moderately high and stable at 0.684 from 30 – 120 minutes. The zones adjacent to the lobby zone of release become infected quickly. However, the zones that are farther away and serviced by the uninfected AHU remain protected owing both to the distance and filtration.

The ER is vulnerable to a chemical agent because the baseline design did not incorporate preventive measures for that type of threat. Reduction in the FBP during the initial 10 minutes of the attack is partially due to the contaminant release occurring over that time period. The FBP can vary depending on the duration of the release event. Additionally, the sharp FBP decrease in the VX and sarin can be attributed to the AHUs servicing of a common interior zone. As a result of that design, a release in the lobby zone will penetrate into the interior ER zones and throughout the entire facility.

Representative results of this study are shown in Figures 2 and 3. Because the baseline designs have a BCPI of zero, their FBP values are located on the y-axis. Figure 2 plots FBP and corresponding BCPI for all three chemical agents at 2 minutes. Figure 3 represents the performance for anthrax at 2, 10, and 30 minutes. Using the BCPI as the financial measure reflects the total redesign cost increases for the first year. For the purposes of this study, only two plots are presented. However, the flexible nature of this methodology allows for multiple plots that can incorporate MEPI or OMPI individually or together, along with multiple combinations of contaminants and time durations.

In Figure 2, the FBP for all three chemical agents is greater than 0.78 at 2 minutes. The chemical with the highest FBP and lowest lethality is hydrogen cyanide, followed in descending order by sarin and VX. This difference is reflected in the plot as VX shows the lowest FBP level for all redesign options. A subsequent plot at 10 minutes reveals the slight decline in the FBP for all three agents, which then drops to zero after 30 minutes for several redesign options. Simply increasing the amount of OA in the current AHU configuration would not prevent the spread of VX and sarin. VX, with the highest lethality, caused the FBP values to decline the sharpest. The CB sensor system that detects and responds at 5 minutes helps to keep the FBP levels of sarin above 0.67 for the 100% OA, AHU shutdown, and separate exhaust options during the first 30 minutes. The fast reaction time combined with sarin's moderate lethality contributed to its protection level. For both VX and sarin, the additional AHU results in an FBP greater than 0.86 over the entire 120 minutes. Having a separate AHU for the lobby zones, the point of release, produces the most consistent FBP value. The FBP for hydrogen cyanide remains high for all options, with only the lobby zones receiving significant contamination levels.

The hospital ER has a higher level of protection against biological agents. Over the entire 120 minutes, the FBP for all redesign options does not fall below 0.68 for anthrax and ricin. This performance is consistent with its intended design to minimize the spread of biological particulate agents. The use of MERV 14 particulate filters is instrumental in removing these agents. In Figure 3, the anthrax results are provided to show the slight variation in redesign options. All redesign options at 2, 10, and 30 minutes resulted in a FBP greater than 0.68. Shutting down the AHU at 5 minutes consistently provided the highest FBP over the entire duration. For both anthrax and ricin, the additional AHU provided no significant improvement.

Based on this study, the redesign options sustaining the highest FBP over the entire 120 minute duration and corresponding lowest first-year BCPI for each contaminant are listed in Table 7.

Table 7. Recommended Redesign Option Based Contaminant

Contaminant	Redesign Option	BCPI	FBP
VX	Additional AHU at 20/80	0.627	0.868
Sarin	Additional AHU at 20/80	0.627	0.868
Hydrogen Cyanide	Change OA/RA to 40/60	0.025	0.989
Anthrax	Shutdown AHU at 5 min	0.468	0.868
Ricin	Shutdown AHU at 5 min	0.468	0.978

Table 7 results are based on one set of criteria. The methodology described throughout this study allows for numerous combinations of criteria to be analyzed together, providing the decision maker with an efficient means of comparing multiple design options and CB protection performance.

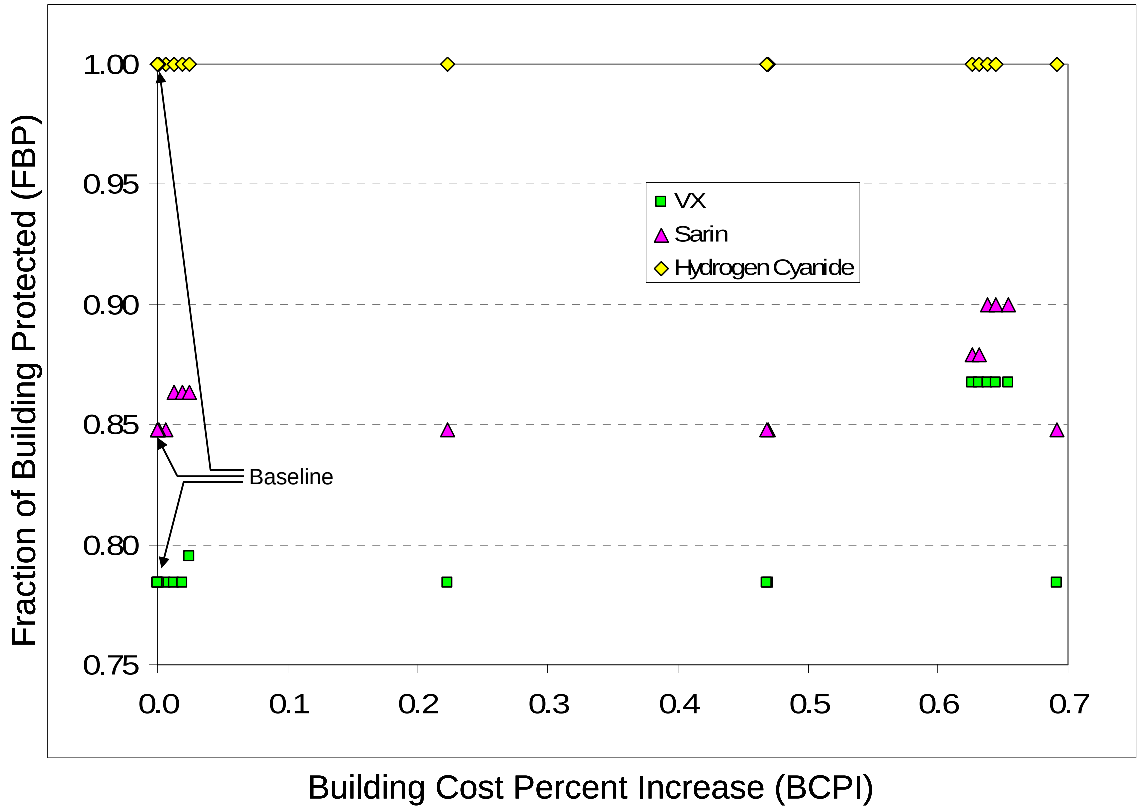

Figure 2. FBP at 2 minutes for chemical contaminants

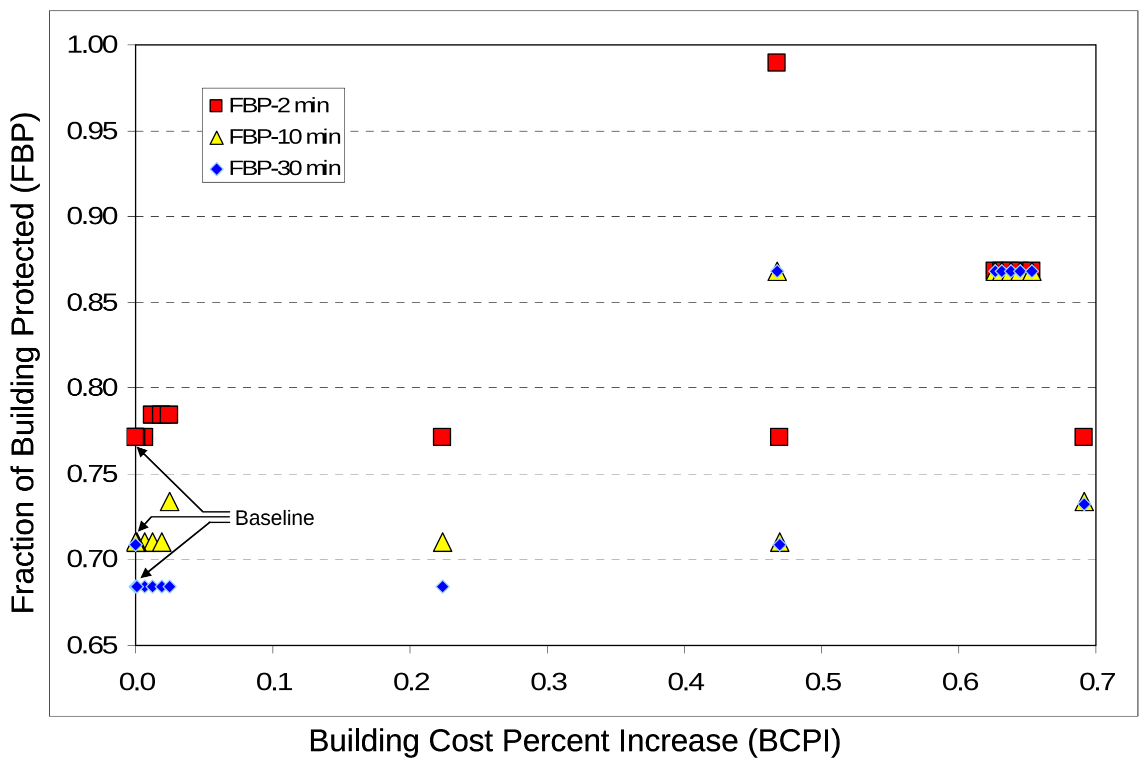

Figure 3. FBP for anthrax

5. CONCLUSIONS

Presented in this study is a methodology that incorporates multizone simulation with analysis of financial implications to assess design options for protecting buildings against internal CB threats. The methodology is flexible and can be adapted for new construction as well as renovations. Tailoring this assessment methodology to the specific building and the associated constraints is essential for developing accurate and realistic results.

The results presented here pertain to the specific hospital emergency room used in the case study. Although the facility is a complex structure, its performance may not be representative of more conventional buildings. For example, the hospital uses MERV 14 particulate filters by design, for purposes of infection control, and this significantly improves the building's protection against a biological threat. In conventional construction, however, MERV 7 – 10 filters are typically used, and those offer a lower level of protection. Additionally, the separation of public access and secure areas within a building can significantly impact the results. In defense industrial facilities, secure areas are generally access-controlled, but physical barriers and separate AHUs or exhaust systems for the open-access areas is not standard. These aspects of facility design can significantly influence how quickly a CB threat spreads through a building interior.

The fraction of building protected is not a unique value tied to one specific MEPI, OMPI, or BCPI. For any particular design option and its corresponding financial percent increase, a different FBP level can be achieved. However, as shown in Figures 2 and 3, increasing the BCPI will not always result in an increased FBP. In some cases, adding more expensive CB protection measures can actually reduce the overall FBP.

Further research is planned to investigate additional CB protection options and the ability to model them accurately within the multizone program. The myriad of possible combinations and permutations of protective design options presents a challenge. A more rigorous statistical analysis is planned to include hypothesis, correlation, and significance testing. The goal is to provide all building designers with greater capability to assess and protect their buildings against CB threats.

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